PMNSFitter
An experiment-driven neutrino oscillation global fit

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1 Introduction

With the measurement of θ_{13} by the Daya Bay, RENO, Double-Chooz, T2K and MINOS experiments, oscillations between the three active neutrino flavors driven by both mass-squared differences are solidly established. Precise determination of those mass-squared differences as well as of the three angles in the PMNS mixing matrix is essential to enable the measurement of the remaining unknowns in the three-neutrino mixing scenario: the neutrino mass hierarchy and the δ_{CP} phase. To achieve the highest possible precision on these measurements with existing and future experiments, a combination of all available data from neutrino oscillation experiments is required. In general, existing global fitting efforts are based on energy spectra or χ^2/likelihood surfaces published or supplied by each experiment. The provided information does not allow the fits to account for systematic differences between the Monte Carlo generators used by each experiment in their simulations. Furthermore, the simple addition of χ^2/likelihood surfaces does not account for possible correlations between systematics, and Collaborations do not or rarely provide detailed descriptions of the effects of systematic uncertainties in their analyses.

These shortcomings can be remedied with a deeper involvement of neutrino experiments in the global fitting process so that accurate accounting for systematics and other experimental characteristics such as detector efficiencies can be included. PMNSFitter is a novel effort to determine the neutrino oscillation parameters using all available data from neutrino oscillations measurements. It is modeled on past successful global fit efforts, such as the LEP Electroweak Working Group, and aims to be driven by experimental inputs.

2 Fitting Strategy and Goals

A new framework is being developed based on a likelihood obtained from the 3-neutrino flavor oscillation probabilities. This likelihood can then be sampled in the 3-flavor parameter space using frequentist or Bayesian methods. We are presently exploring Markov Chain Monte Carlo and Population Monte Carlo methods to scan the 3-neutrino flavor parameter space efficiently. Detailed information from each experiment would serve as inputs to the code. This information would be provided by experiment liaisons and would include data, Monte Carlo predictions and information about systematic uncertainties. Correlations between systematics of an experiment will be taken into account in the fit. We also plan to carry out studies to determine potential correlations between systematics of different experiments.

The primary goal of PMNSFitter is to produce measurements of the neutrino oscillation parameters in the three-flavor scenario with the smallest possible uncertainties, while ensuring those uncertainties are as realistic as possible. As new data becomes available, the fits would be updated with both the new data and any improvements in understanding relevant systematic uncertainties. A secondary goal consists of interfacing the fitter with a package like GLoBES, to help assess the physics reach of future experiments or proposed projects.

3 Working Group Organization

We anticipate the PMNSFitter Working Group to be structured into: experiment liaisons; advisory panel; framework developers; and a small group of people tasked with running the fits and producing results. The latter group will possibly overlap with the group of framework developers. The experiment liaisons would represent the interests of each experiment inside the Working Group and would be expected to seek consensus from their Collaboration on which information would be released to the Working Group. They would provide this information as inputs to the fitter in a commonly agreed format, as well as relevant details on the experimental setup and/or analysis that could contribute to improvements on the fit results. The advisory panel would be composed of interested members of the community and would help guide and direct the Working Group progress. Only the group running the fits will have access to the full data set for all experiments and data from those experiments will not be made available to a wider audience without approval from the corresponding liaison. The data from all experiments would be stored using encryption technology to prevent unauthorized access. Public release of the global fit results will be subject to approval by experiment liaisons. The format and content of the author's list of a potential global fit publication will be addressed when input from liaisons regarding preferences of their respective Collaborations is available.

4 Common Input Format

Ideally, the data provided by each Collaboration would follow a common format wherever possible. As an example, in the case of the MINOS experiment, template histograms are stored in ROOT files. In the specific case of the MINOS ν_μ disappearance analysis, each ROOT file contains:

- 1D histogram with reconstructed neutrino energy spectrum for selected data at the far detector;
- 2D histogram with reconstructed vs true neutrino energy for the predicted signal;
- 2D histogram with reconstructed vs true neutrino energy for the wrong-sign background resulting from $\bar{\nu}_\mu$ CC interactions reconstructed with a negative muon;
- 2D histogram with reconstructed vs true neutrino energy for the background resulting from potential ν_τ CC interactions;
- 1D histogram with reconstructed shower energy for the NC background.

The 2D histograms allow for correct application of oscillation weights to both signal and background to compute the total oscillated MC prediction. Such a ROOT file is provided for each MINOS run period and each different beam configuration such as low-energy or high-energy running. Furthermore, equivalent ROOT files are available for each energy dependent systematic considered in the MINOS analysis. For each systematic, a set of 4 files includes simulation histograms shifted by $\pm 1\sigma$ and $\pm 2\sigma$, allowing the fitter to interpolate between histograms to obtain intermediate values of the scale factors applied used when fitting with systematics as nuisance parameters. Each experiment would also provide a covariance matrix encoding information about correlations between uncertainties. For experiments measuring atmospheric neutrinos, information on L/E and zenith angle for each event may be required to correctly compute oscillated predictions to compare to the data.

5 Summary

PMNSFitter is a new effort to maximize the precision on neutrino oscillation parameters that can be extracted from all available data. It aims to be driven by experimental inputs and therefore its success hinges on fostering a collaboration between existing neutrino oscillation experiments and on agreement of the experiments to supply data and simulation information in more detailed formats. The Working Group is keeping a mailing list at pmns_fitter@fnal.gov and will begin holding regular meetings between developers and experiment liaisons in the near future.

6 Expressions of Interest

This section lists members of the neutrino community that expressed interest in collaborating with the new global fitting effort presented here. The experiment and institutional affiliations are listed along with their names in alphabetical order. In the initial phase of this effort, the listed people would help convey the objectives of the PMNSFitter Working Group to their collaborations and begin the process by which each collaboration would appoint an experiment liaison to represent their interests.

Name	**Affiliation**	**Collaboration**
Adam Aurisano	University of Cincinnati	NOνA/MINOS+
Andrew Blake	Cambridge University	MINOS+
Frederik Beaujean	MPI München	Phenomenologist
Son Cao	University of Texas at Austin	MINOS+
Douglas Cowen	Penn State	IceCube/DeepCore
Stefano Dusini	INFN Padova	OPERA
Gary Feldman	Harvard University	NOνA
Karsten Heeger	University of Wisconsin-Madison	Daya Bay
Patrick Huber	Virginia Tech	Theorist/Phenomenologist
Randy Johnson	University of Cincinnati	Daya Bay/MicroBooNE
Karol Lang	University of Texas at Austin	MINOS+/SuperNEMO
Bryce Littlejohn	University of Cincinnati	Daya Bay
Francesca Di Lodovico	Queen Mary University London	T2K
Camillo Mariani	Virginia Tech	Double Chooz/MicroBooNE
Mark Messier	Indiana University	NOνA
Ryan Patterson	Caltech	NOνA
Robert Plunkett	Fermilab	MINOS+
Boris Popov	LPHNE/JINR	T2K/NA61
Masato Shiozawa	Kavli IPMU	T2K/Super-Kamiokande
Alex Sousa	University of Cincinnati	NOνA/MINOS+
Jenny Thomas	University College London	MINOS+/SuperNEMO
Nikolai Tolich	University of Washington	SNO/SNO+
Filippo Varanini	INFN Padova	ICARUS
Alfons Weber	University of Oxford	T2K
Roger Wendell	University of Tokyo, ICRR	Super-Kamiokande